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Project No. NY 112 004-1
Technical Note N-107
26 March 1952

"TRACTION TESTS IN SNOW AT THE SIERRA TEST SITE, FEBRUARY-MARCH 1952"

S. J. Weiss

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SUMMARY

On the basis of quantitative field testing in the limited environmental condition of the Laboratory's snow test site, it was demonstrated that the Tucker Sno-Cat No. 443, although weighing less than the M29C (Weasel) was able to develop the greater drawbar pull. This relative performance can be explained by the greater track contact area utilizing the cohesive component of the snow shear strength.

Attempts to predict the performance of these vehicles by means of the Soil Truss, an exploratory trafficability instrument developed by the Laboratory, have demonstrated that the initial snow shear strength measured by this instrument is not as directly indicative of the tractive effort developed by a tracked vehicle as is the corresponding measurement in sandy soils. It is believed that the collapse in snow structure and strength subsequent to its initial loading precludes the use of this instrument in its present form for the direct evaluation of tractive performance that has been applied in the case of these soils. The comparatively high initial static strength of the snow as compared with that after the collapse of structure is proposed as a possible field of exploitation.

INTRODUCTION

Historical Background

Previous tests of the Soil Truss Mark II have demonstrated the ability of this instrument to provide a shearing-strength classification of the settled snow surfaces existing in the vicinity of NAVCERELAB's cold weather station, the Sierra test site near Bishop, California[1]. Although this instrument was developed primarily for estimating the trafficability of soil, the military importance of estimating trafficability of snow dictated trials in this perhaps more complex medium although the theoretical basis for vehicle mobility has not been fully evolved.

The theoretical investigations that have formed the background for the development of the Soil Truss have as yet been confined mainly to only one aspect of the soil-vehicle relationship essentially limited to the investigation of the state of stresses and the equilibrium of forces which are assumed at the moment of soil failure. There has resulted a formulation of the factors affecting the tractive effort produced by a tracked vehicle in soil that has been closely corroborated by experiments[2]. This is primarily a function of the shearing resistance of the surface layers and, consequently, these initial investigations in snow have been confined to that portion of the snow cover near the surface.

Statement of the Problem

The mobility of vehicles can be estimated on the premise that movement is possible only when tractive effort exceeds the movement resistance. Previous work in vehicle-mobility research in soil has brought out the dependence of tractive effort upon two mechanical soil characteristics similar in concept to the characteristics of cohesion and angle of friction of classical soil mechanics. The Soil Truss has been developed for field determination of these characteristics. The objective of the phase of the work described in this report is to determine whether the performance of vehicles in snow is similarly related to the Soil-Truss characterization of the shearing resistance of snow.

METHODS

Tests were conducted in accordance with the Memorandum of Procedure, Project NY 112 004-1, Sierra Test Site, Winter 1952 Field Testing, Low Pressure Tracks and Wheels. This memorandum is incorporated in this report as Appendix A. The tests consisted essentially of providing a mobile drawbar load for the test vehicle. This mobile load was effected by a M29C (Weasel) equipped with a fifth-wheel speedometer for determining the true speed of advance over the snow. The coupling of the test and dynamometer vehicles is shown in Figures 1 and 2. The fifth-wheel speedometer is shown in Figure 3.

A strain-gauge drawbar included in the towline between the vehicles (Figure 4) with its accompanying amplifier and meter allowed a continuous indication of the drawbar pull.

A magneto tachometer, connected to the ignition system of the test vehicle (Figure 5) aided the driver of the test vehicle in maintaining a prescribed engine speed for the duration of the test. The complete set of vehicle instrumentation components is shown in Figure 6.

Measurements in the snow supplemented the above instrumentation of the vehicles. As shown in Figure 7, snow characteristics, as determined by the Standard Snow Instruments made up by the National Research Council of Canada, were recorded as well as the classification provided by the Soil Truss.

RESULTS

Surface snow characteristics at the time of the tests are compiled in Figures 8 through 13. Each snow condition described was taken at a typical area along the test path of the vehicle.

Graphs of drawbar pull vs track slippage for the M29C are shown in Figure 14. Similar graphs of the performance of the Sno Cat are shown in Figure 15. A comparison of the Sno Cat and M29C performance under identical conditions are shown in Figure 16. The estimated and actual performance of the vehicles are tabulated in Figures 17 and 18. The simple shear failure equation is utilized neglecting the effects of lateral flow. The data enabling the plotting of the performance curves are tabulated in Figures 19 through 22.

Figure 17 demonstrates that the tractive effort developed by the vehicle while moving in the snow is much less than the static strength indicated by the Soil Truss and that developed during static (tracks locked) drawbar-pull tests of the vehicle. The causes of this discrepancy are probably a combination of the following effects:

1. Additional sinkage and motion resistance during track slippage.

2. The surface snow measured by the Soil Truss and utilized during the static drawbar tests being different in strength than the snow at the depth of vehicle sinkage.

3. A breakdown in the initial snow structure caused by the action of the vehicle track.

It is interesting to note (See Figure 17) that the results of the static drawbar test and the estimated tractive effort, H, of the M29C in the snow conditions as shown in Figure 10 are in close agreement. In this case the Soil-Truss readings were taken in the undisturbed surface snow. A light snow fall between the tests recorded in Figures 10 and 11 prevented the taking of Soil-Truss readings in other than the compacted path of the vehicle, and thus the computed and static test performances for the snow condition shown in Figure 10 are not as directly comparable.

Figures 14 and 15 demonstrate clearly that the performance of a vehicle in snow continually varies with the variations of the snow caused by aging, temperature changes, and the associated changes in snow structure and moisture content. In general, under the test-site conditions performance improved with increased aging of the snow.

Figure 16 indicates that the Tucker Sno Cat developed greater drawbar pull than the M29C in identical snow conditions. However, Figure 18 demonstrates that no new basic vehicle-soil relationship is required to explain this performance. The grip-failure concepts involving vehicle weight and tract area can be used to predict the percentage of the increased performance expected.

CONCLUSION

On the basis of the vehicle tests conducted in the limited environmental condition of the Sierra Site the following conclusions are presented:

1. As contrasted to tests in soil, the static snow-strength indications of the Soil Truss do not allow a direct quantitative estimate of the tractive permance of a moving vehicle perhaps because of the greater complexity of the structure of snow.

2. Soil Truss indications, however, allow a relative indication of the performance of vehicles.

3. As contrasted to the action of vehicles in soil, the locked-track (static) drawbar pull is considerably higher than the maximum developed with the track in motion.

4. The Tucker Sno Cat, although weighing less than the M29C, developed greater drawbar pull than the M29C, but this relative performance can be explained by the greater track-contact area, utilizing the cohesive component of the snow shear strength.

RECOMMENDATIONS

On the basis of these tests and the conclusions derived from them it is recommended that:

1. Consideration be given to the development of a Soil Truss modification allowing recording of shearing strength versus displacement in order to obtain an indication of other than the initial static strength of the snow.

2. Consideration be given to the development of a snow vehicle with a track principle to exploit the comparatively high static strength of the snow.

REFERENCES

1. NAVCERELAB Technical Note N-075, <u>Use of the Soil Truss Mark II in Determining the Shearing Strength Characteristics of a Snow Cover</u> by S. J. Weiss, 23 January 1952.

2. Aberdeen Proving Ground Third Report on OCO Project No. 771-698 (RESTRICTED), <u>Effect of Grouser Height on the Tractive Effort of a Vehicle</u> 21 March 1949.

Figure 1. M29C Pulling Dynamometer Vehicle (another M29C).

Figure 2. Tucker Sno-Cat No. 443 Pulling Dynamometer Vehicle.

Figure 3. Fifth Wheel Speedometer.

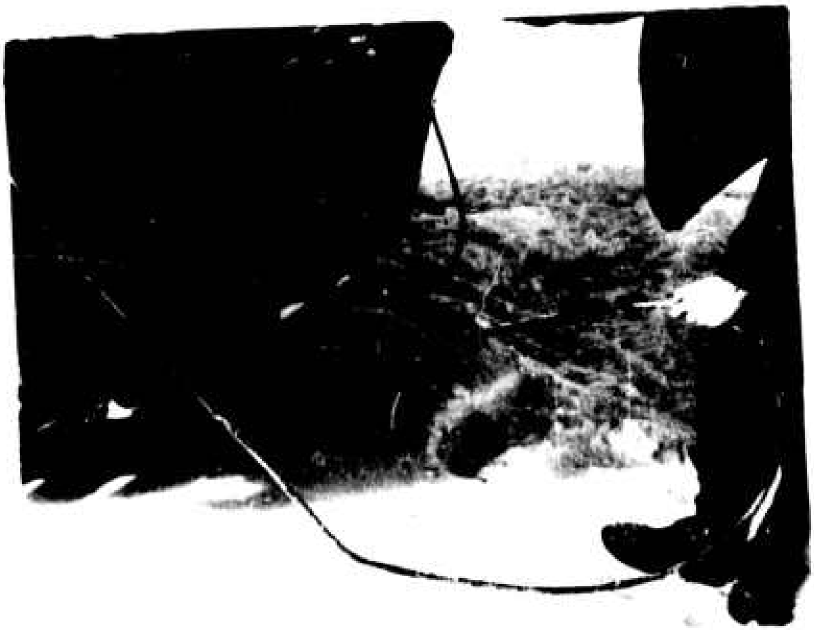


Figure 4. Strain Gauge Drawbar.

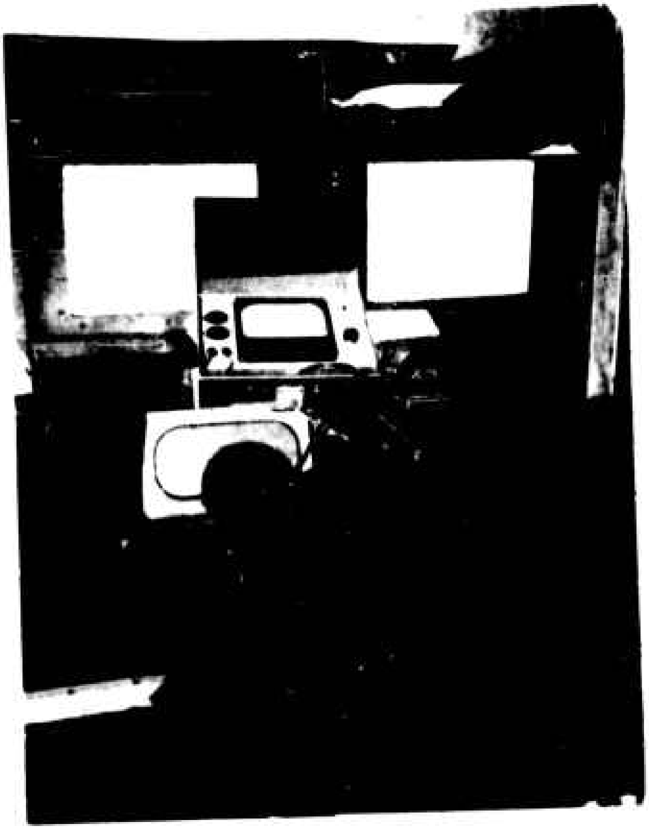


Figure 5. Magneto-Tachometer.

Figure 6. Test Instrumentation.

Figure 7. Taking Snow Measurements.

FIGURE No 8 2-28-62 @ M86

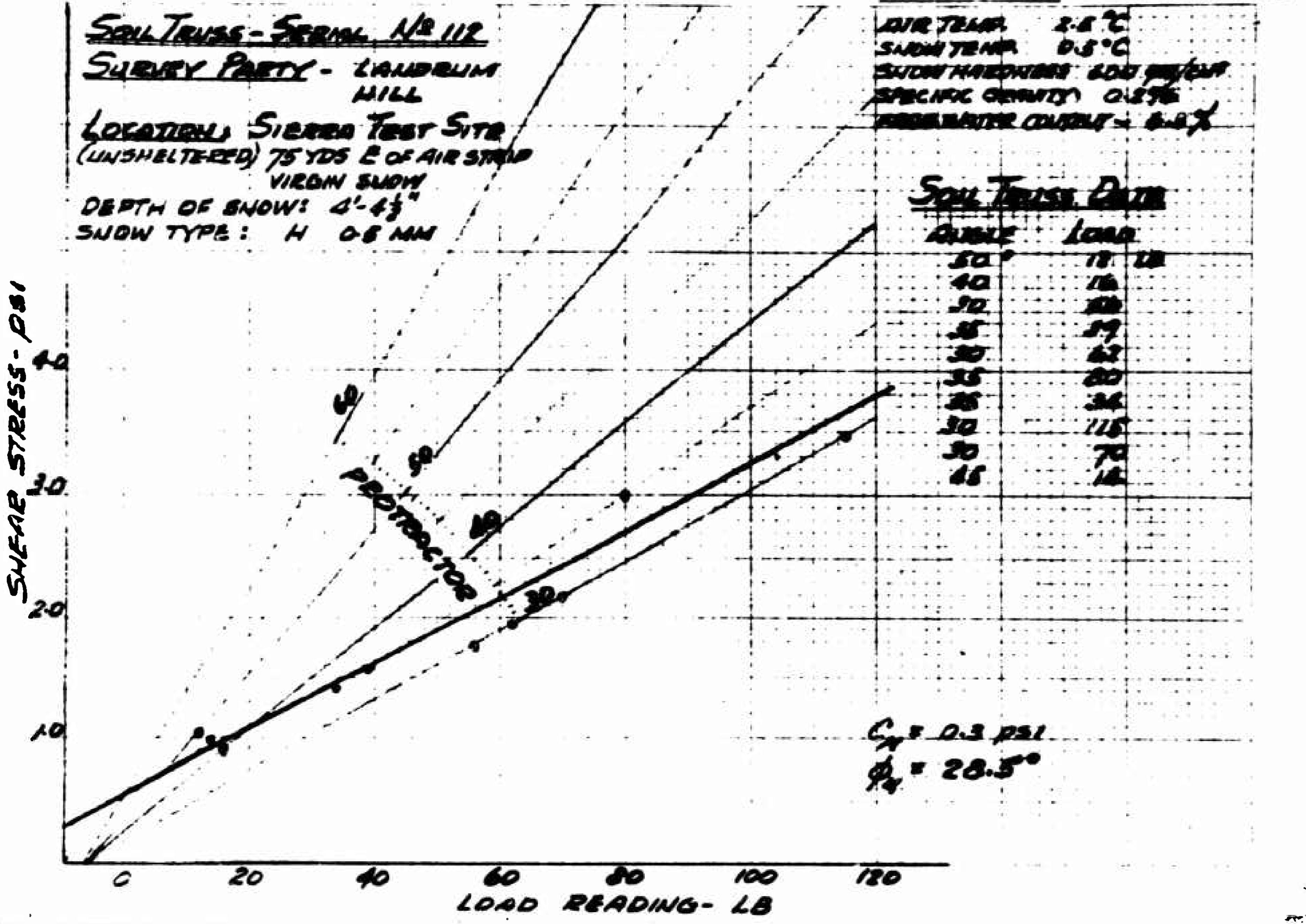


FIGURE № 9 2-29-52 0830 TO 0910

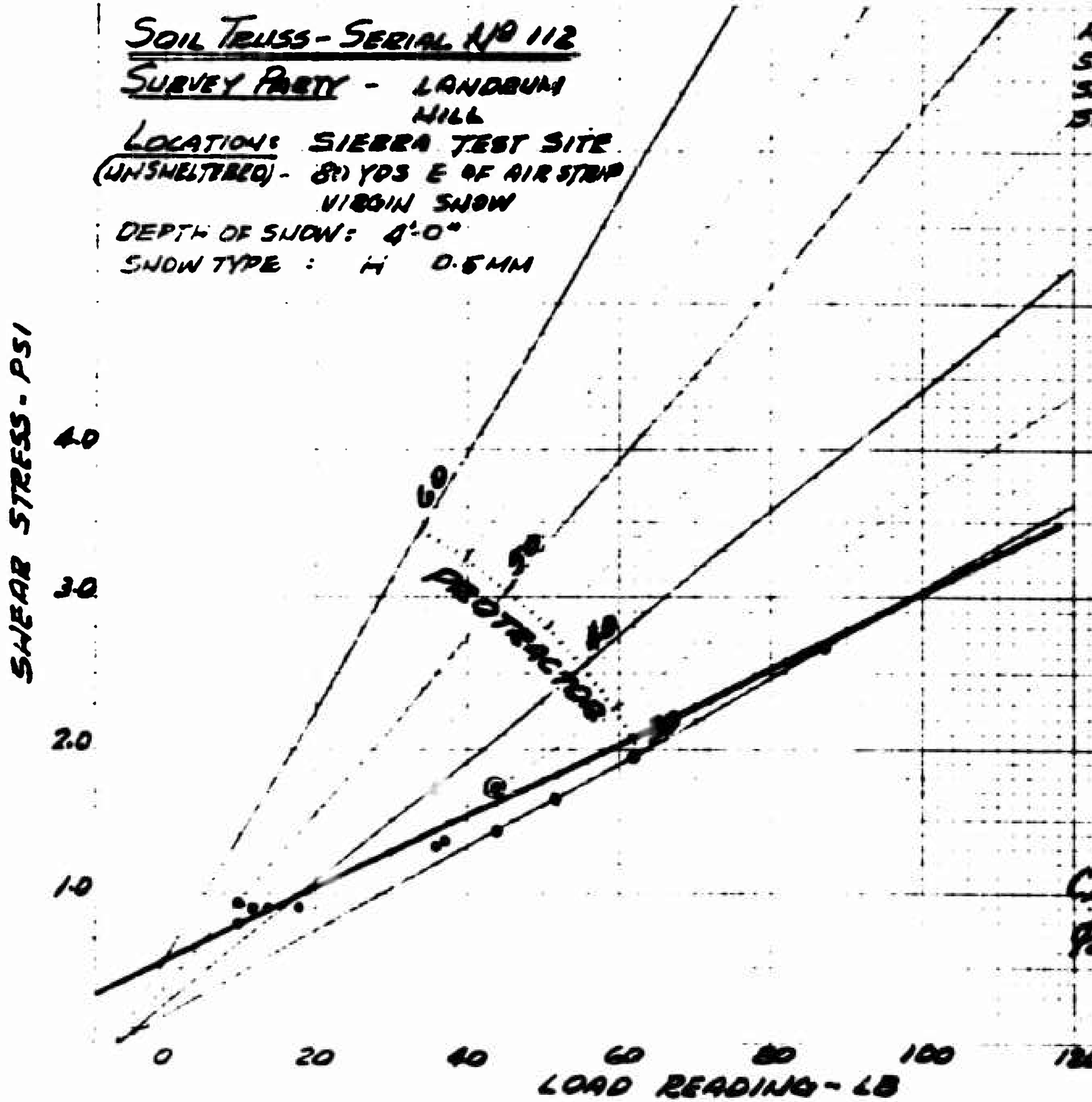
AIR TEMP. - 0.7°C
SNOW TEMP. -11.1°C
SNOW HARDNESS. 5700 gm/cm²
SPECIFIC GRAVITY. 0.436

SOIL TRUSS - SERIAL № 112

SURVEY PARTY - LANDBUM HILL

LOCATION: SIERRA TEST SITE
(UNSHELTERED) - 80 YDS E OF AIR STRIP
VIRGIN SNOW

DEPTH OF SNOW: 4'-0"
SNOW TYPE : H 0.5 MM



SOIL TRUSS DATA

ANGLE	LOAD
35°	42 LB
40	36
45	12
50	10
30	44
32½	37
37½	18
42½	14
45	10
30	52
35	42
35½	36
30	62
30	87

$C_{st} = 0.32$ PSI
$\phi_{st} = 26.5°$

FIGURE No 10 2-29-52 1335 to 1400

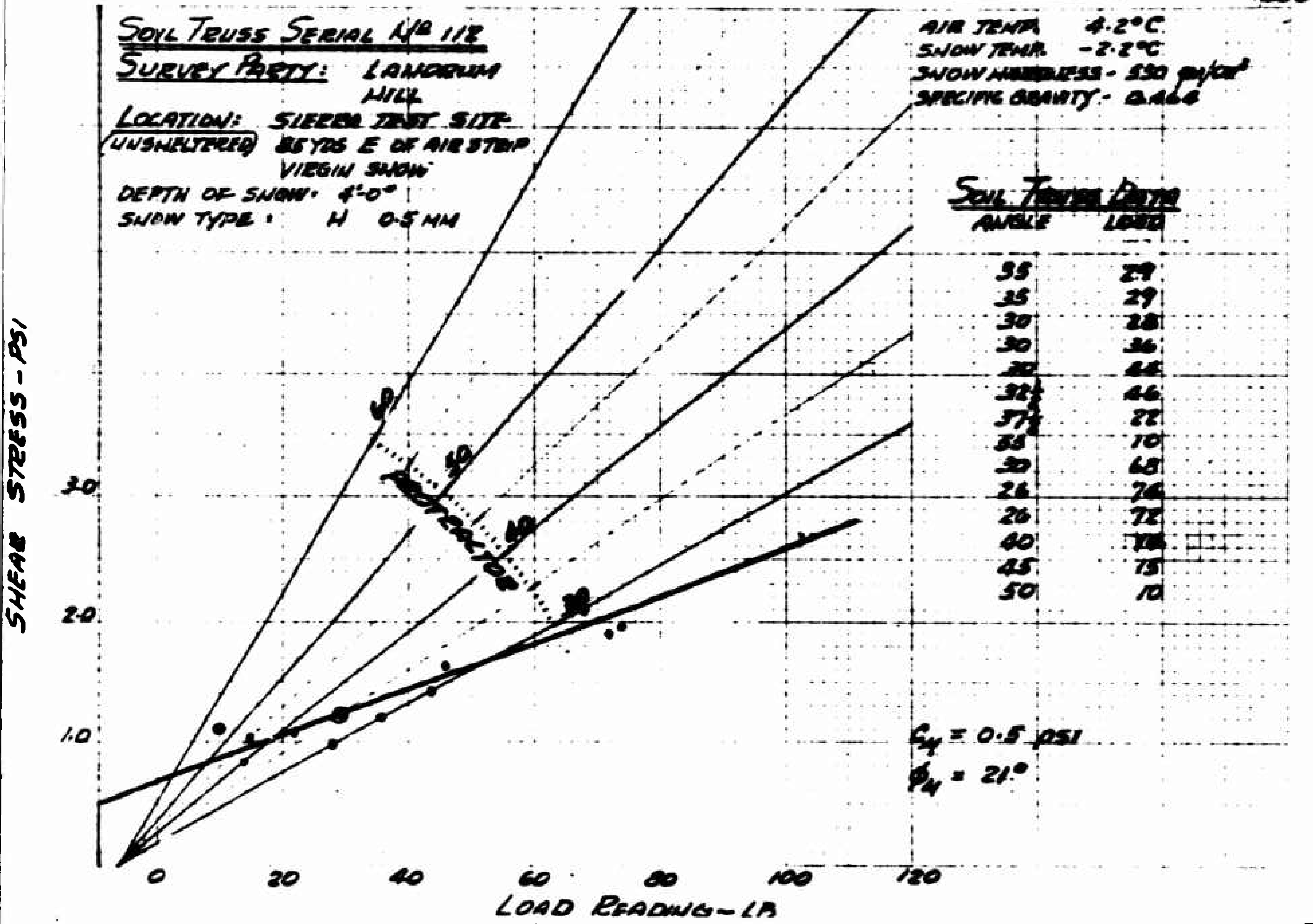


FIGURE NO 11 3-3-52 0900 TO 0920

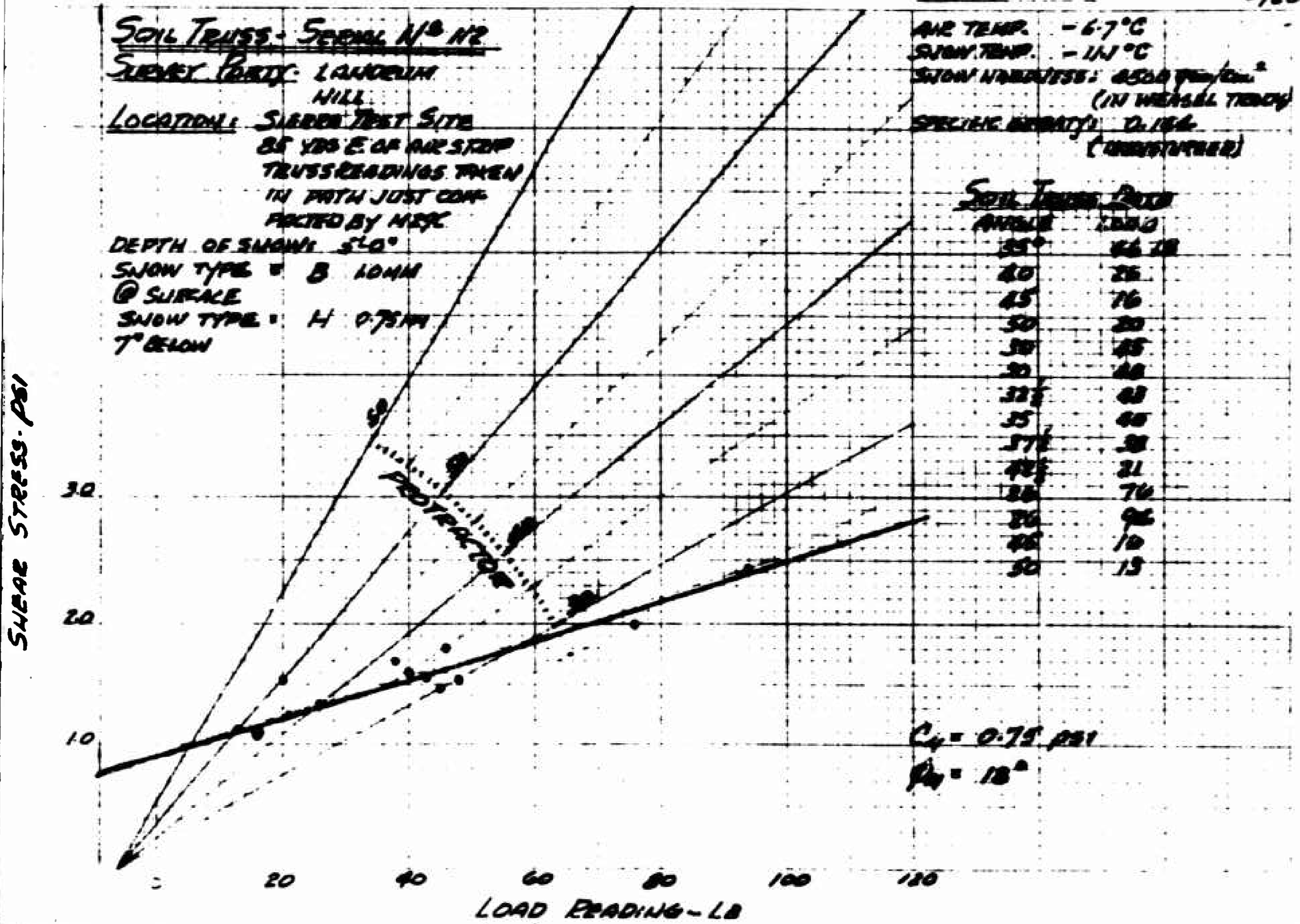


FIGURE No 12 3-4-52

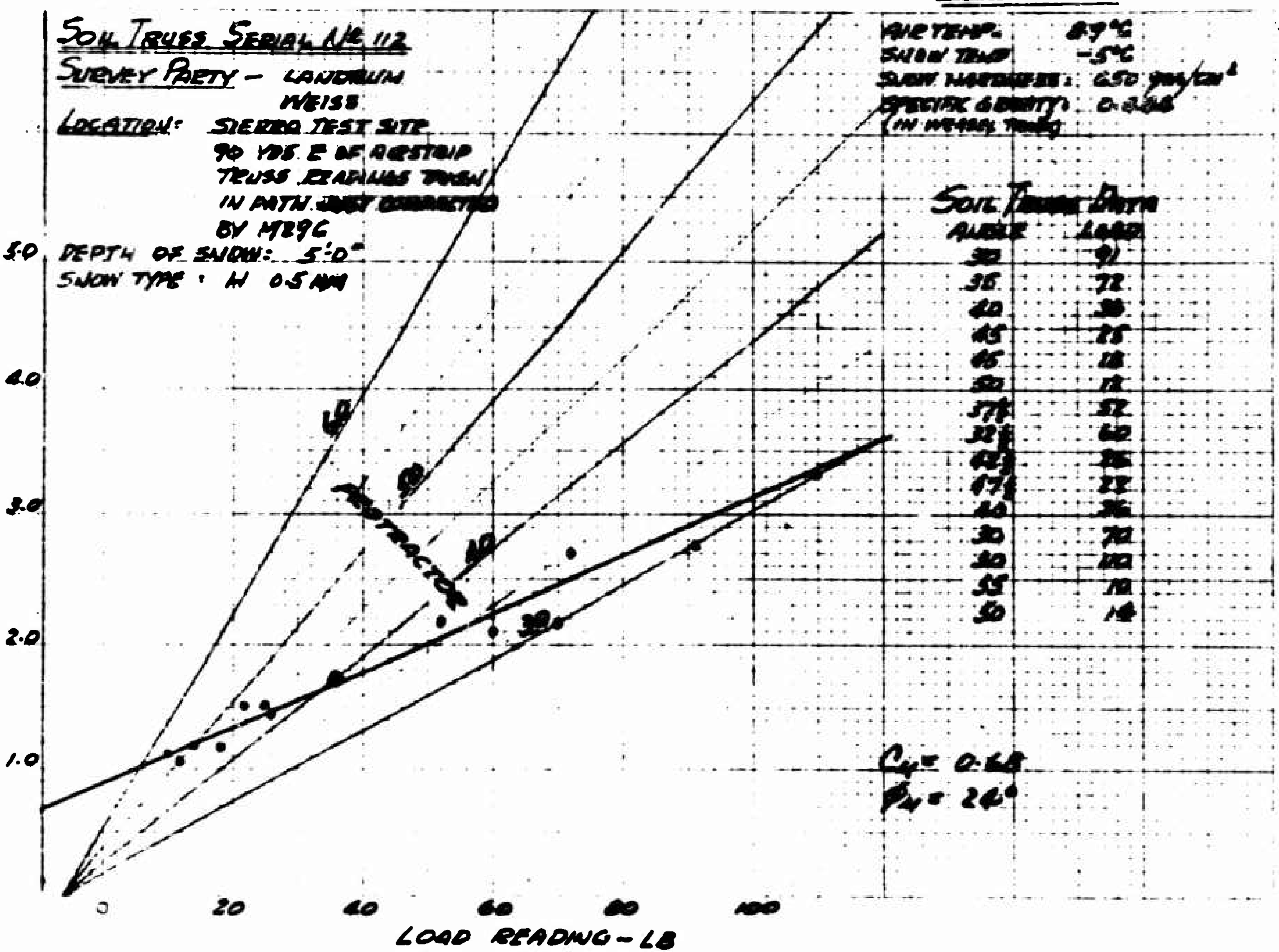
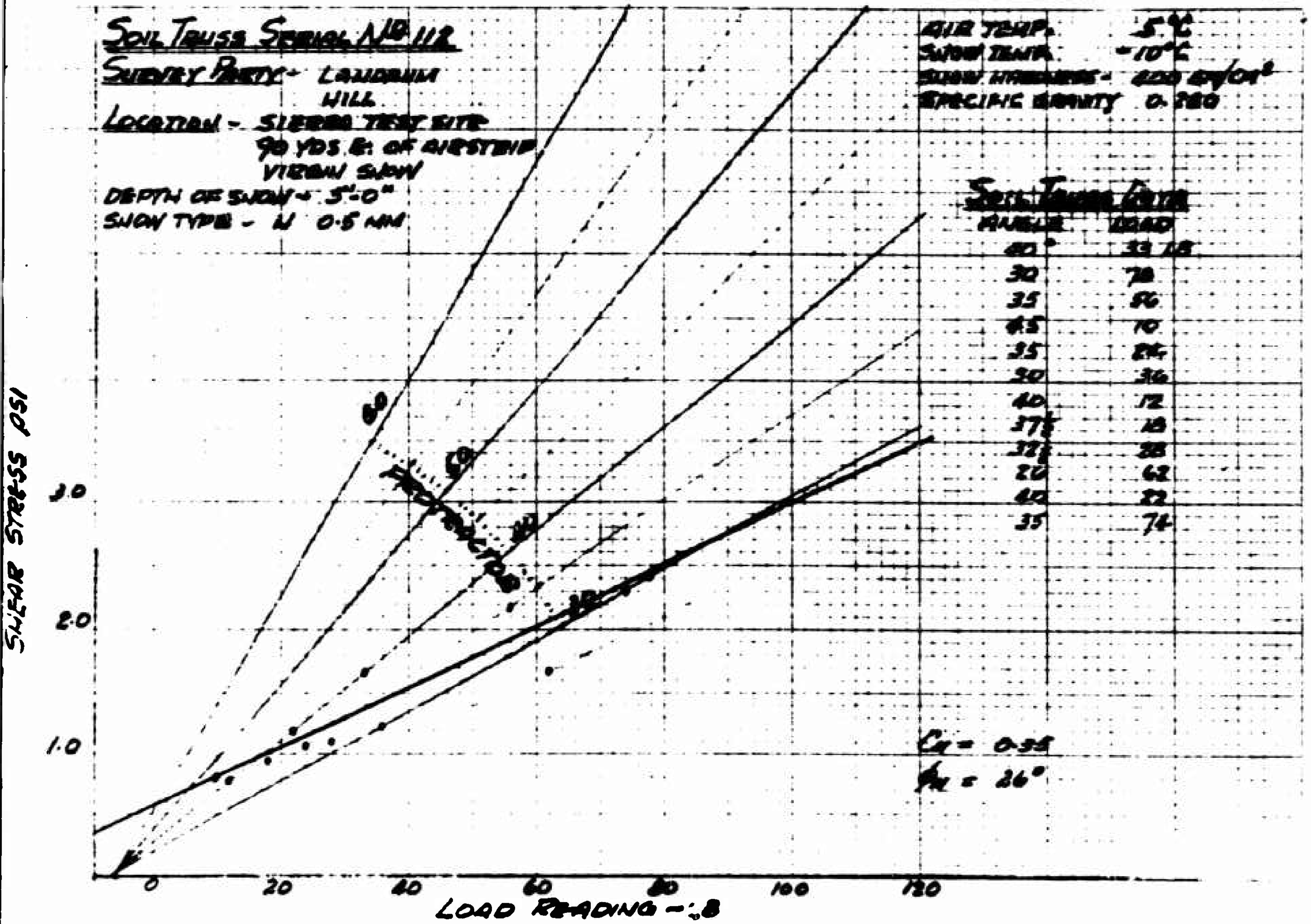


FIGURE No 13 3-5-52 0920 0950



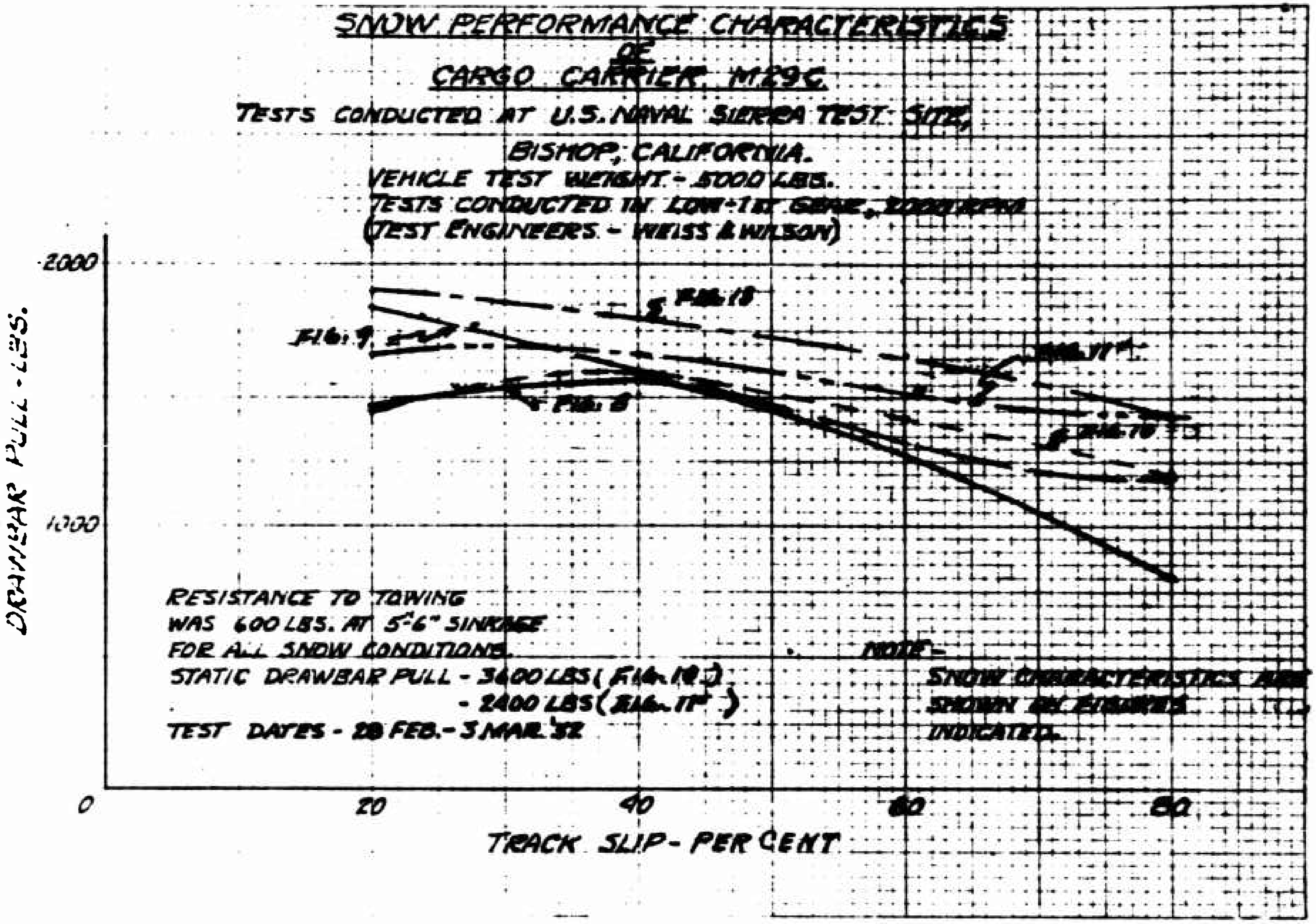
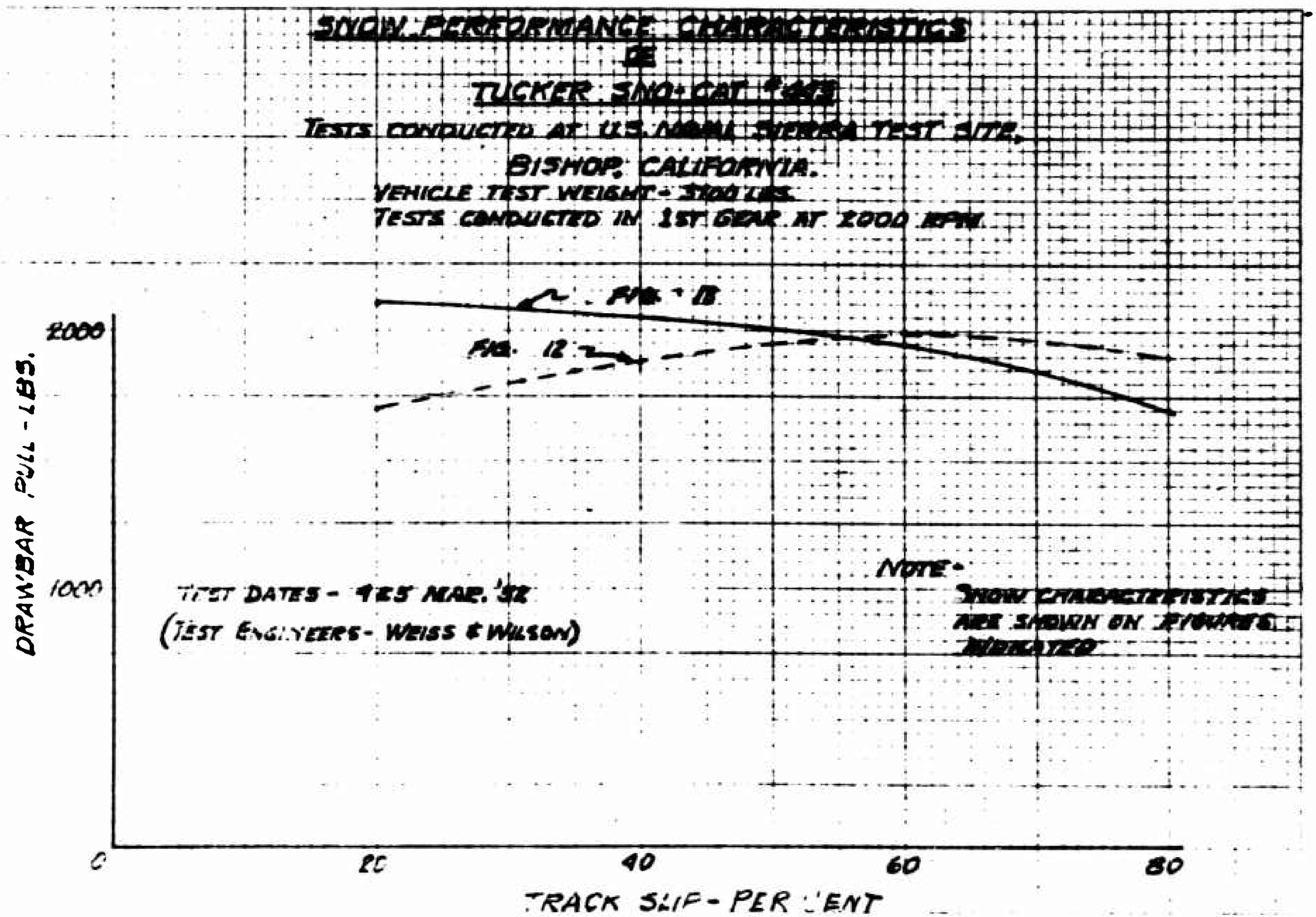
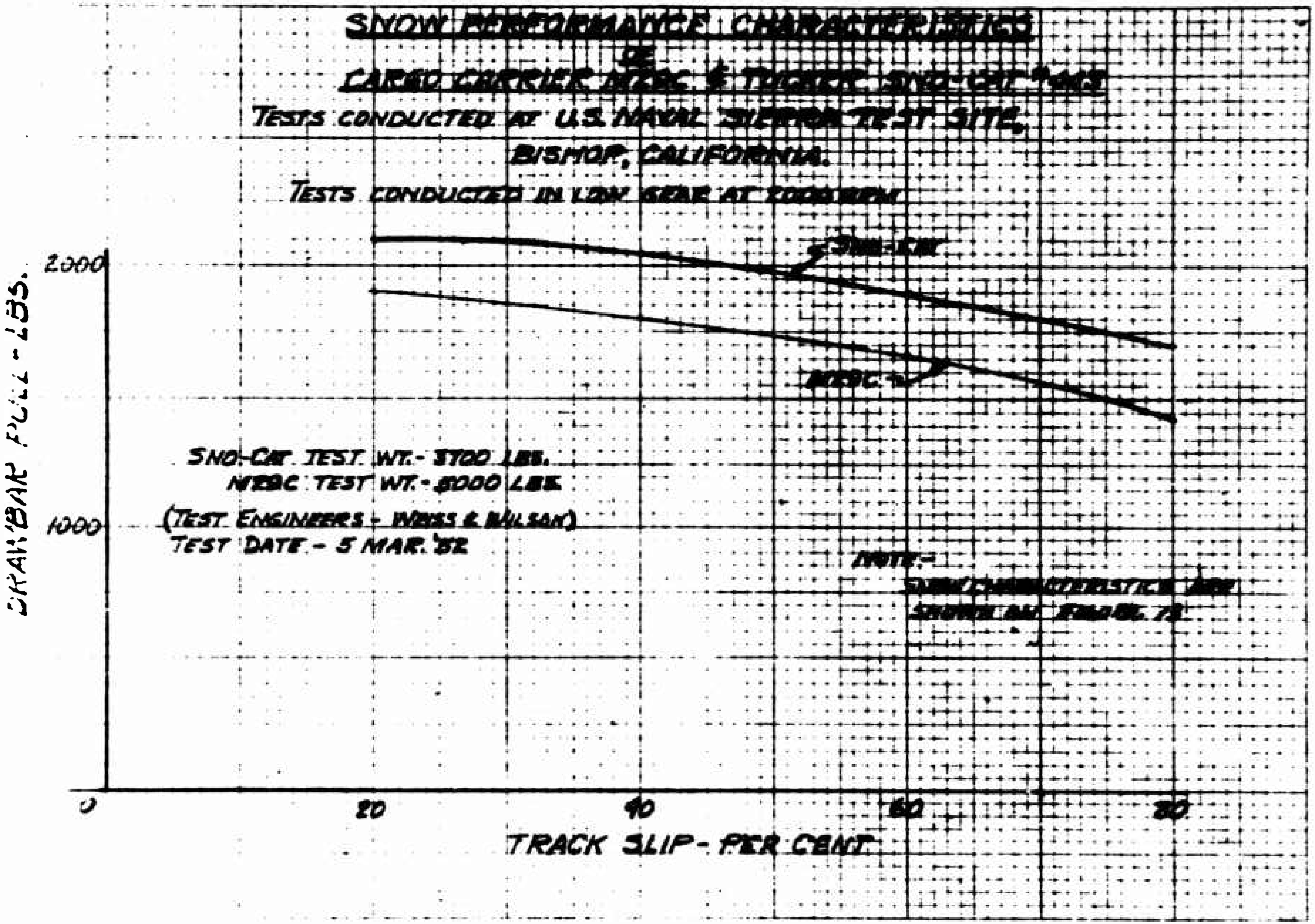

SNOW PERFORMANCE CHARACTERISTICS
OF
CARGO CARRIER M29C
TESTS CONDUCTED AT U.S. NAVAL SIERRA TEST SITE,
BISHOP, CALIFORNIA.
VEHICLE TEST WEIGHT - 5000 LBS.
(TEST ENGINEERS - WEISS & WILSON)
FIG. 9
FIG. 8
2000
1000
0
20
40
60
80
DRAWBAR PULL - LBS.
TRACK SLIP - PER CENT
RESISTANCE TO TOWING
WAS 600 LBS. AT 5"-6" SINKAGE
FOR ALL SNOW CONDITIONS.
STATIC DRAWBAR PULL - 3600 LBS
- 2400 LBS
TEST DATES - 28 FEB. - 3 MAR. '52
NOTE -
SNOW CHARACTERISTICS ARE
SHOWN ON FIGURES
INDICATED.

FIG. 14



SNOW PERFORMANCE CHARACTERISTICS
OF
TUCKER SNO-CAT
TESTS CONDUCTED AT U.S. NAVAL SIERRA TEST SITE,
BISHOP, CALIFORNIA.
VEHICLE TEST WEIGHT
TESTS CONDUCTED IN 1ST GEAR AT 2000 RPM.
FIG. 13
FIG. 12
2000
1000
DRAWBAR PULL - LBS.
TEST DATES - MAR. '52
(TEST ENGINEERS - WEISS & WILSON)
NOTE -
SNOW CHARACTERISTICS
ARE SHOWN ON FIGURES
INDICATED
0
20
40
60
80
TRACK SLIP - PER CENT

FIG 5



SNOW PERFORMANCE CHARACTERISTICS
OF
CARGO CARRIER M29C & TUCKER SNO-CAT
TESTS CONDUCTED AT U.S. NAVAL TEST SITE,
BISHOP, CALIFORNIA.
TESTS CONDUCTED IN LOW GEAR
SNO-CAT
M29C
SNO-CAT TEST WT. - 3700 LBS.
M29C TEST WT. - 8000 LBS.
(TEST ENGINEERS - WEISS & WILSON)
TEST DATE - 5 MAR. '52
NOTE -
DRAWBAR PULL - LBS.
2000
1000
0
20
40
60
80
TRACK SLIP - PER CENT

FIG 16

FIGURE 17

PERFORMANCE OF M29C

Vehicle Weight, V = 5000 lb.

Track Area, A = 3120 Sq.in.

	Snow Condition (Refer to Fig. No.)	8	9	10	11	Remarks
	ϕ	28.5°	26.5	21.0°	18°	
	c psi	0.30	0.32	0.5	0.75	
	tan ϕ	.544	.499	.384	.325	
	V tan ϕ	2720	2490	1920	1625	
	c A	936	1000	1560	2330	
*	H	3656	3490	3480	3955	Estimated Tractive Effort
	Towed Resistance R lb	600	600	600	600	
▲	DBP est lb	3056	2890	2880	3355	Estimated DBP
	DBP test lb	1575	1840	1600	1690	Maximum DBP during Track Slippage
	Actual DBP/Est.DBP	.523	.638	.555	.502	
	Static DBP test lb			3600	2400	Tracks locked
	Static DBP/Est. H			1.04	.606	

* $H = V \tan \phi + cA$

▲ $DBP_{est} = H - R$

FIGURE 18

COMPARATIVE PERFORMANCE OF M29C AND SNO CAT NO. 443 IN SNOW CONDITION DESCRIBED IN FIGURE 13

	$\phi = 26^{o}$ $c = 0.35$ psi	
	Weasel M29C	Sno Cat 443
V lb	5000	3700
A sq in.	3120	5400
V tan ϕ	2440	1800
c A	1090	1890
* H lb	3530	3690
Max. DBP lb during test	1900	2100

Ratio of estimated tractive effort $= \frac{3530}{3690} = 0.96$

Ratio of actual DBP $= \frac{1900}{2100} = 0.91$

* $H = V \tan \phi + cA$

FIGURE 19

MOBILITY TESTS - SIERRA SITE

VEHICLE: Cargo Carrier M29C TEST WEIGHT: 5000 DATE & TIME: 28 Feb'52 1340-1400

COURSE: 75 yds E of Air Strip OPERATOR: Weiss & Wilson

REMARKS: Snow condition as per Figure 8

TRACK/WHEEL SLIP

20%		40%		60%		80%	
Meter	Drawbar Pull	Meter	Drawbar Pull	Meter	Drawbar Pull	Meter	Drawbar Pull
0.16	1600	0.16	1600	0.12	1200	0.09	900
0.13	1300	0.17	1700	0.15	1500	0.07	700
0.15	1500	0.14	1400	0.11	1100	0.08	800
		0.16	1600	0.13	1300	0.08	800

Movement resistance @ 50% equiv. = 600# (Sinkage = 5-7")

FIGURE 20

MOBILITY TESTS - SIERRA SITE

VEHICLE: Cargo Carrier M29C TEST WEIGHT: 5000 DATE & TIME: 29 Feb '52 0830-0900 1430-1500

COURSE: 75 yds E. of Air Strip OPERATOR: Weiss & Wilson

TRACK/WHEEL SLIP

0830-0900

Snow Condition as per Figure 9	20% Meter	20% Drawbar Pull	40% Meter	40% Drawbar Pull	60% Meter	60% Drawbar Pull	80% Meter	80% Drawbar Pull
	0.2	2000	0.17	1700	0.13	1300	0.12	1200
	0.19	1900	0.15	1500	0.15	1500	0.15	1500
	0.18	1800	0.15	1500	0.14	1400	0.12	1200
	0.17	1700	0.18	1800	0.12	1200	0.08	800
	0.18	1800	0.15	1500	0.12	1200	0.12	1200

M.R. = 600# @ 50% Slip equiv.

1430-1500

Snow Condition as per Figure 10	20% Meter	20% Drawbar Pull	40% Meter	40% Drawbar Pull	60% Meter	60% Drawbar Pull	80% Meter	80% Drawbar Pull
	0.16	1600	0.15	1500	0.15	1500	0.11	1100
	0.15	1500	0.15	1500	0.13	1300	0.12	1200
	0.14	1400	0.17	1700	0.14	1400	0.14	1400
	0.13	1300	0.17	1700	0.15	1500	0.11	1100

Static D.B. w/locked tracks = 3600#

FIGURE 21

MOBILITY TESTS - SIERRA SITE

VEHICLE: Cargo Carrier M29C TEST WEIGHT: 5000 DATE & TIME: 3 Mar '52 0830-0900

COURSE: 75 yds E. of air strip OPERATOR: Weiss & Wilson

REMARKS: Snow condition as per Figure 11.

TRACK/WHEEL SLIP

20%		40%		60%		80%	
Meter	Drawbar Pull	Meter	Drawbar Pull	Meter	Drawbar Pull	Meter	Drawbar Pull
0.16	1600	0.15	1500	0.15	1500	0.14	1400
0.17	1700	0.18	1800	0.15	1500	0.13	1300
0.18	1800	0.16	1600	0.14	1400	0.13	1300
0.15	1500	0.15	1500	0.15	1500	0.13	1300
0.17	1700	0.19	1900	0.17	1700	0.18	1800

M.R. = 600# @ 50% slip equiv.

Static DB w/tracks locked = 2400#

There had been a snowfall of approx. 6" since test on 29 February 1952.

FIGURE 22

MOBILITY TESTS - SIERRA SITE

VEHICLE: Tucker Sno-Cat / Cargo Carrier M29C   TEST WEIGHT: 3700# / 5000#   DATE & TIME: 4 Mar'52 0900-100(

COURSE: 75 yds E. of air strip   OPERATOR: Weiss & Wilson

TRACK/WHEEL SLIP

Snow Condition as per Figure 12

20%		40%		60%		80%	
Meter	Drawbar Pull	Meter	Drawbar Pull	Meter	Drawbar Pull	Meter	Drawbar Pull
SNO-CAT							
0.15	1500	0.19	1900	0.18	1900	0.18	1600
0.19	1900	0.18	1800	0.20	2000	0.20	2000

M.R. @ 50% equiv. = 1300#

5 MAR '52

Snow Condition as per Figure 13

0.21	2100	0.20	2000	0.17	1700	0.17	1700
0.21	2100	0.21	2100	0.19	1900	0.17	1700
CARGO CARRIER M29C							
0.19	1900	0.17	1700	0.15	1500	0.12	1200
0.19	1900	0.18	1800	0.17	1700	0.16	1600
0.19	1900	0.19	1900	0.18	1800	0.15	1500

APPENDIX A

PROJECT NO. NY 112 004-1

Memorandum of Procedure

SIERRA TEST SITE

WINTER 1952 FIELD TESTING

LOW PRESSURE TRACKS AND WHEELS

U. S. Naval Civil Engineering
Research and Evaluation Laboratory
Port Hueneme, California
24 January 1952

U. S. NAVAL CIVIL ENGINEERING
RESEARCH AND EVALUATION LABORATORY
CONSTRUCTION BATTALION CENTER
Port Hueneme, California

NT4-59/NY 112 004-1
771/SJW/hb

23 January 1952

MEMORANDUM OF PROCEDURE, PROJECT ORDER NO. NY 112 004-1 JOB ORDER NO. 23812

Subj: Project NY 112 004-1, Low Pressure Tracks and Wheels

1. GENERAL

The project of Low Pressure Tracks and Wheels has arisen through the need of the Marine Corps for operating tracked and wheeled equipment over adverse terrain during combat missions. The project was assigned to the U.S. Naval Civi Engineering Research and Evaluation Laboratory, Port Hueneme, California RDB car No. 112 004 dated 31 December 1949 with further assignment for prosecution and report to the Equipment Research Department of the Laboratory.

2. PURPOSE

In view of the extensive and diverse efforts that have been directed by military, government and private agencies towards the improvement of vehicle mobility, the objects of this project are:

A. To review, analyse and evaluate all studies, reports, recommendations and other such data as may exist from any possible source relating to the problems of vehicle mobility.

B. To establish such specific research, development and test programs not being adequately covered for Navy Construction Battalion and Marine Corps Shore Party operations by programs of other defense agencies.

C. To develop and test specific equipment and equipment components which indicate superior mobility characteristics.

D. Studies are to include:

(1) Land vehicles of special design for operation in adverse soils.

(2) Standard land vehicles modified to improve mobility in adverse soils

(3) Amphibious vehicles.

(4) Auxiliary equipment such as sleds, prefabricated roadways, soil stabilization, etc.

(5) Soil studies and the relation of vehicle design to soil characteristics.

(6) General study of component refinements to increase tractive effort, reduce rolling resistance, etc.

3. PROJECT PHASE SCHEDULED FOR WINTER 1952

The testing program will be carried out at or near the NAVCERELAB's Sierra Test Site, near Crestview Lodge, Bishop, California on State Highway 395 with the participation of the U.S. Army Ordnance Corps Mobility Research Laboratory of Aberdeen Proving Ground, Maryland. The tests will consist of quantitative dynamic drawbar pull tests in snow over the full slip range of two vehicles:

A. The Weas. l

B. The Tucker Sno-Cat

which embody differing track and suspension concepts.

In addition to evaluation of the relative merits of the two tracks, it will be attempted to relate the performance of these vehicles to the shearing strength classification of the snow cover obtained by means of the Soil Truss Mark II, an instrument developed by the Laboratory for estimating the trafficability of soil.

4. TEST EQUIPMENT

A. Weasel - provided by NAVCERELAB, STS)
) Test vehicles
B. Sno-Cat - provided by Tucker Sno-Cat Company)

C. Dynamometer Vehicle - Additional Weasel or Sno-Cat provided by NAVCERELAB, STS.

D. Fifth wheel speedometer assembly with indicating instrument and connecting cables.) Provided by Mobility Research Laboratory, Aberdeen Proving Ground.

E. Magneto Tachometer assembly with indicating instrument and connecting cables.)

F. Strain gauge drawbar with indicating meter, excitation source and connecting cables.)

G. Standard Snow Instruments made up by National Research Council of Canada - provided by NAVCERELAB.

H. Soil Truss Mark II Kit - provided by NAVCERELAB.

I. Rigging and gear required for assembling test and dynamometer vehicles - provided by NAVCERELAB, STS.

5. TEST PERSONNEL AND ASSIGNMENT

Project Engineer - Recorder-Snow instrumentation.
APG participant - Strain gauge drawbar - Fifth wheel and tachometer instrumentation.
Laboratory Technician - Soil Truss measurements
Driver - Tucker Sno-Cat)
Driver - Weasel)Sea Bee personnel presently stationed at
Driver - Dynamometer vehicle) Sierra Test Site

6. ARRANGEMENTS FOR TESTING

A. The tests are to be conducted on level ground in a minimum of 36 inches of snow. The test area shall be undisturbed, and be at least 600 ft long and 75 ft wide.

B. The strain gauge drawbar shall be coupled between the test vehicle and the dynamometer vehicle and suitable electrical connections provided for the excitation source and the external meter.

C. The fifth wheel assembly shall be installed at the rear of the dynamometer vehicle so that it follows in one of the tracks compacted by the dynamometer vehicle. The indicating meter should be so placed that it and the external meter indicating the drawbar pull can be read by the same observer and by the driver of the dynamometer vehicle.

D. The magneto tachometer is to be properly connected to the distributor of the test vehicle. The indicating meter is to be located in the cab of the test vehicle so that it is readily visible to the driver.

E. Prior to the actual testing all indicating meters are to be set on proper range and initially balanced where required.

7. TEST PROCEDURE

A. A test vehicle engine speed, to be maintained by the driver of the test vehicle during all drawbar pull tests, will be designated by the Project Engineer.

B. The Project Engineer, prior to each test run, will also designate a fifth wheel speedometer reading to be maintained by the driver of the dynamometer vehicle.

C. Immediately prior to the start of vehicle testing the following characteristics of the undisturbed snow cover are to be determined, using National Research Council of Canada Standard Snow instrumentation.

(1) Specific gravity.

(2) Hardness.

(3) Snow temperature.

(4) Air temperature.

(5) Snow type and grain size.

(6) Free water content.

(7) Depth of snow cover.

and NAVCERELAB Soil Truss classification.

D. With the vehicles and equipment rigged in accordance with paragraph 6 with vehicles proceeding in a straight line and with the vehicle speeds in accordance with paragraphs 7A and 7B, the strain gauge drawbar indication is to be noted and recorded. This procedure shall be repeated with increasing slip of the test vehicle (dependent upon 7A and 7B) until the maximum drawbar pull has been achieved.

F. Each test run is to be performed in undisturbed snow. Care shall be taken that the test vehicle is not operating in snow disturbed by previous tests.

F. The snow measurements of paragraph 7C shall be repeated in the track of the test vehicle. If required the surface of the track may be carefully cleared of snow loosened by the grousers of the test vehicle's tracks.

8. ADDITIONAL INFORMATION

A. The weight and loading condition of the test vehicle shall be recorded on the proper data sheet prior to each series of tests.

B. Each test vehicle is to be supplied with an Operational and Maintenance Sheet. If trouble develops in the equipment, the operator is to record all details of the trouble.

C. Whenever possible, photographs are to be taken, both still and motion, of the test procedures and technique. A complete photographic record is to be made of the test area.

9. TECHNICAL CONTROL

Technical control of all testing operations will be carried out as prescribed in Laboratory Order 3-51, dated 22 August 1951, to Department Heads, Division Directors and Military Coordinators; from Commanding Officer.

STANLEY J. WEISS
Project Engineer
NAVCERELAB, CBC
Port Hueneme, California

APPROVED:

/s/ John T. Tucker
Acting Director, Construction Division

/s/ C.R. Freberg
Head, Equipment Research Department